AeroSense'96
Signal and Data Processing of Small Targets, Conf. 2759
Los Alamos National Laboratory

PARTIAL REMOVAL OF CORRELATED NOISE IN THERMAL IMAGERY

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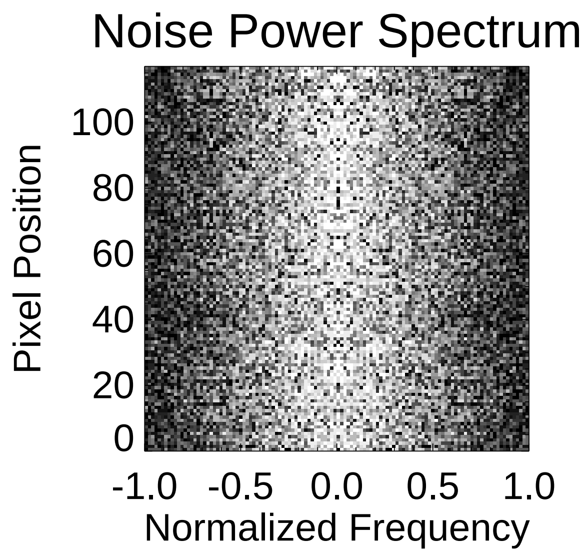
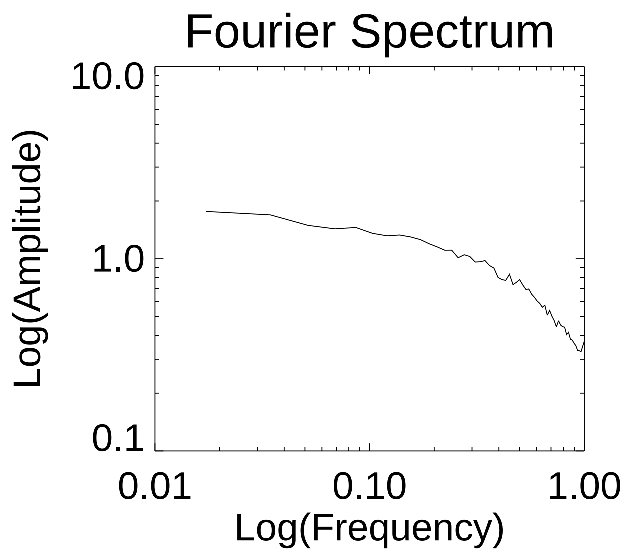
Introduction

Airborne multi-spectral scanners and push broom systems often contain substantial amounts of correlated noise leading to striping visible to an observer. In the past striping has been removed using Fourier analysis techniques, e.g. wedge block filters have been used to improve the qualitative appearance of imagery (Lillesand and Kiefer, 1994). When Fourier analysis was deemed too computationally expensive, simpler spatial filtering methods have been developed (Crippen, 1989).

Source of Correlated Noise in Imaging Systems

- Occurs in scanners and push-broom imagers
- Sources are: detectors, pre-amplifiers and sampling circuits
- Power-law correlated noise has spectrum $N(f) = f^{\alpha}$ where the slope α ranges typically between -0.25 and -2





Example: MCT long wave camera (Inframetrics 600 MCT)

Modeling of Correlated Noise for an Infrared Imager

Steps:

1. Generate uncorrelated (Gaussian) noise signal $s_1(t_k)$ for $x = 1, \ldots, N_x$
2. Compute "Fast Fourier Transform " (FFT) of $s_1(t_k)$ is $S_1(f_x)$
3. Multiply $S_1(f_x)$ with filter response function $F(f_x) = f_x^\alpha$
4. Correlated noise signal: ($\otimes =$ discrete convolution)

$$s_2(t_k) = s_1(t_k) \otimes f(t_k) = FFT^{-1}[S_1(f_x)F(f_x)], \quad x = 1, \ldots, N_x \qquad (1)$$

where $\otimes$ is a symbol for the discrete convolution

Noise signal for an imaging system: ($R_i =$ Gauss. noise)

$$\begin{aligned} N_{noise}(x,y) &= N_{Gaus.}(x,y) + N_{cor}(x,y;\alpha) \\ &= \frac{R_1(x,y)}{STDEV(R_1(x,y))}\frac{1}{SNR_{Gaus.}} + FFT^{-1}\left[FFT\left[\frac{R_2(x,y)}{STDEV(R_2(x,y))}\frac{1}{SNR_{cor}}\right] f_x^\alpha\right], \end{aligned}$$

Algorithm to Partially Remove Correlated Noise

Goal:

Reduce the amount of streaking while minimizing changes of the scene content

Sensor characteristics:

- Scanner: correlated noise in the cross track direction
- Push-broom: correlated noise in the along track direction
- 2-D array: correlated noise in successive frames (not considered here)

Observations:

- Filtering process needs to be carried out only on the frequency axis where the correlated noise appears
- Filtering the region near the origin of the transform image will alter the radiometry of the original image

General filter:

$$F(f_x, f_y) \;=\; 1 - F_1(f_x)F_2(f_y), \quad x = 1, \ldots, N_x;\; y = 1, \ldots, N_y, \qquad (2)$$

where $F_2(f_y \neq 0; \alpha) = f_y^{\alpha}$ and $F_2(f_y = 0; \alpha) = -1$ represents a correction of the correlated noise and α is the slope in a Log-Log plot of the noise spectrum.

(A) Gaussian Filter (used primarily):

$$F_1(f_x; \beta, \sigma) = (1 - \beta)\exp[-(\frac{f_x}{\sigma})^2] + \beta \qquad (3)$$

as a weighting function which preserves spectral components near the origin with a standard deviation σ and offset β which have to be chosen for a particular scene.

Notation:

Filter $F_{PRCNF}(f_x, f_y; \alpha, \beta, \sigma)$, where $PRCNF$ stands for the "Partial Removal of Correlated Noise Filter"

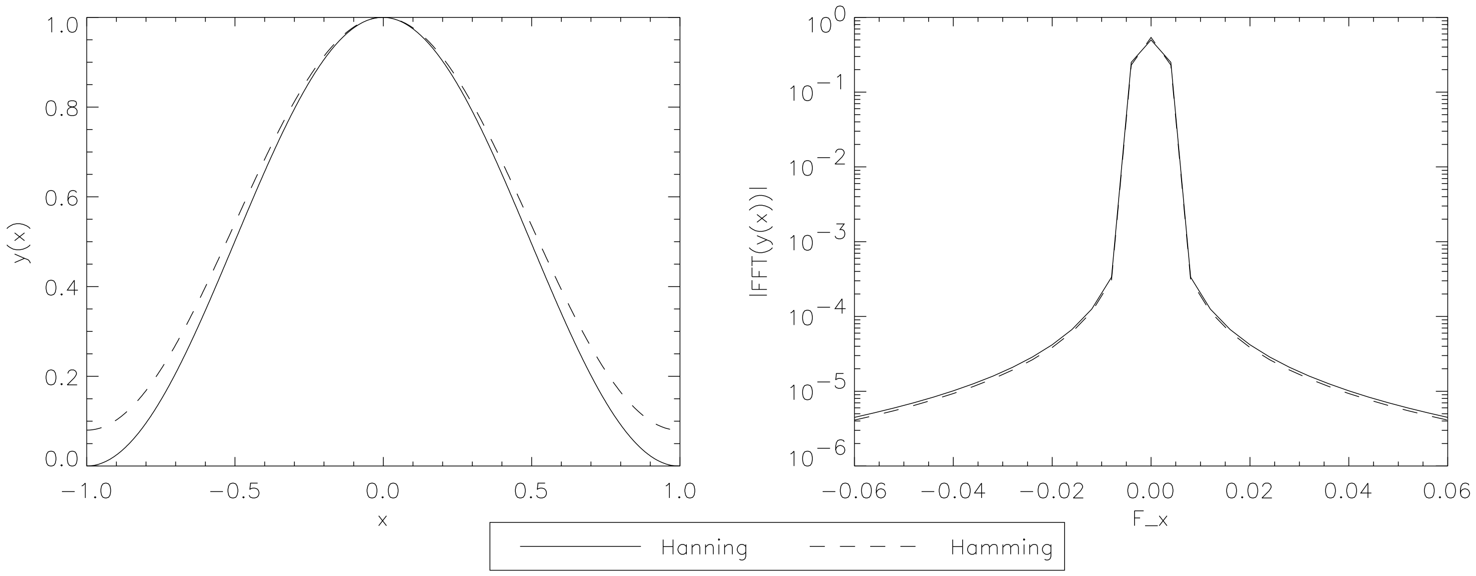
(B) Modified Hanning window function:

$$F_1(f_x;\beta,\gamma) = \left[(\beta-1)\cos\left(\frac{2\pi j}{N_x-1}\right)+\beta\right]^{\gamma} \tag{4}$$

where β is an offset and γ is an exponent to change the width of the peak.

Notes:

- The Hanning window is defined for $\beta = 0.5$ and $\gamma = 1$
- The Hamming window is defined for $\beta = 0.54$ and $\gamma = 1$



OTF and PSF Degradation Effects

Observation:

The partial removal of correlated noise degrades the overall "Optical Transfer Function" (OTF) and "Point Spread Function" (PSF) of the optical system, e.g.:

$$\begin{aligned} OTF_{tot}(f_x, f_y) \;=\; & OTF_{Atmosphere}(f_x, f_y) OTF_{Telescope}(f_x, f_y) OTF_{Motion}(f_x, f_y) \ldots \\ & OTF_{Pixel}(f_x, f_y) OTF_{Electronics}(f_x, f_y) OTF_{PRCNF}(f_x, f_y; \alpha, \beta, \sigma), \end{aligned}$$

where $PRCNF$ stands for the "Partial Removal of Correlated Noise Filter".

Uniform Scenes:

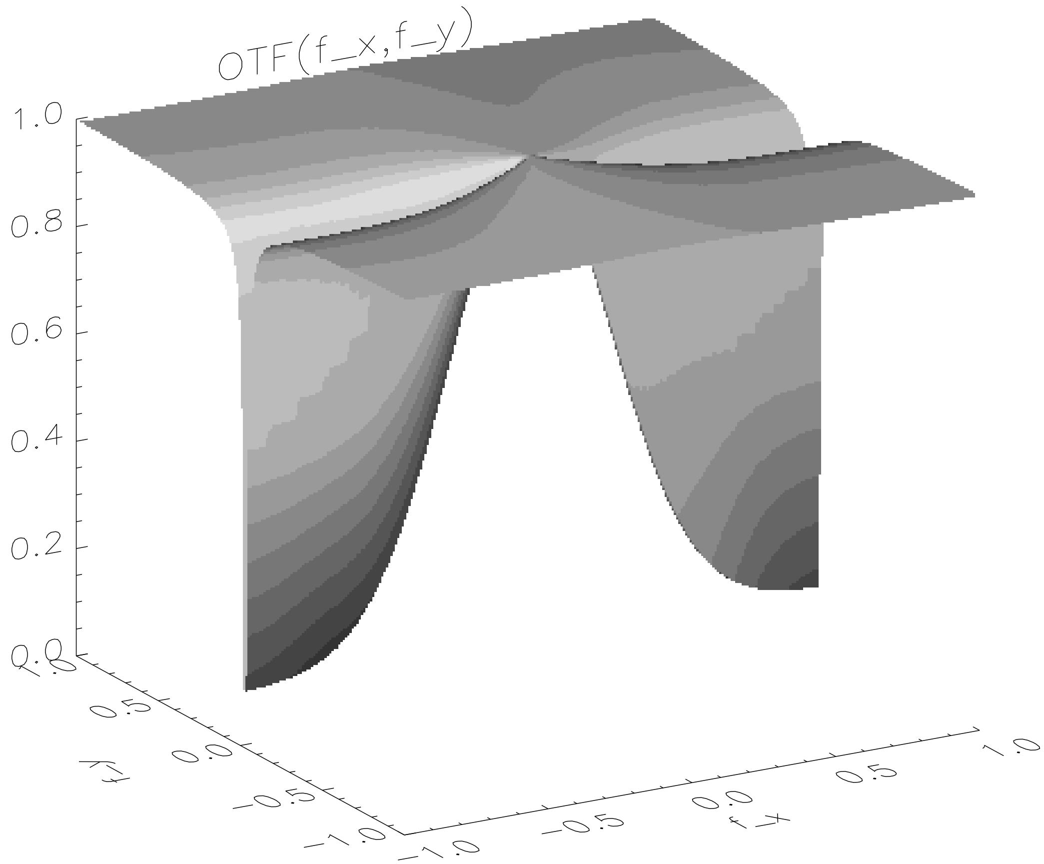
In uniform scenes the "striping" effect can be significantly reduced using the PRCNF method.

Heterogeneous Scenes:

the use of the PRCNF will blur the image somewhat

Example:

OTF of the PRCNF with $\alpha = -1,\ \beta = 0.1$ and $\sigma = 0.1 * N_x$.



Optimizing Method

Question:

How much correlated noise can be removed before the scene content is affected?

Assumptions:

- Let $I_{ref}(x, y)$ be a reference image of the scene of interest with no correlated noise (e.g. taken by a MWIR imager).
- Let $N_{noise}(x, y) = N_{Gaus.}(x, y) + N_{cor}(x, y; \alpha)$ a noise image taken by the LWIR sensor without a scene (e.g. closed aperture, blackbody of similar brightness temperature as the scene).

Steps to partially remove correlated noise:

1. Let $I_1(x,y) = I_{ref}(x,y) + N_{noise}(x,y)$ be a "simulated" scene with both noises (band limited white and correlated) added and filter it with F_{PRCNF} to result in:

$$I_2(x,y) = FFT^{-1}\left[I_1(f_x,f_y)F_{PRCNF}(f_x,f_y;\alpha,\beta,\sigma)\right]$$

2. Compute the RMSE of $(I_2(x,y) - I_{ref}(x,y))$ and select the optimum PRCNF parameters: β_{opt}, σ_{opt} when $RMSE(\beta_{opt},\sigma_{opt}) = Min$

3. Filter the true scene image I_3 which contains similar both kinds of noise similar to the noise image $N_{noise}(x,y)$:

$$I_4(x,y) = FFT^{-1}\left[I_3(f_x,f_y)F_{PRCNF}(f_x,f_y;\alpha,\beta_{opt},\sigma_{opt})\right]$$

Notes:

Highly structured scenes:

The optimum filter will remove only little correlated noise because the scene content would be too much degraded.

Uniform scenes:

Correlated noise will be reduced (e.g. night time LWIR).

Mixed scenes:

Adaptive filter which changes the filter parameters according to scene content (not pursued here).

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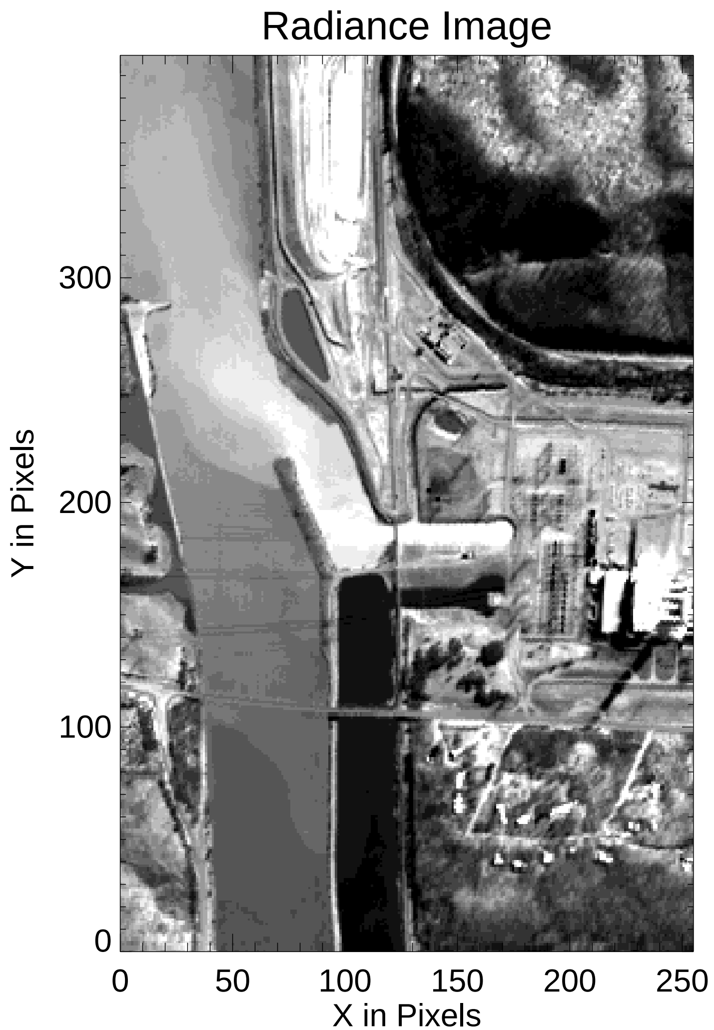
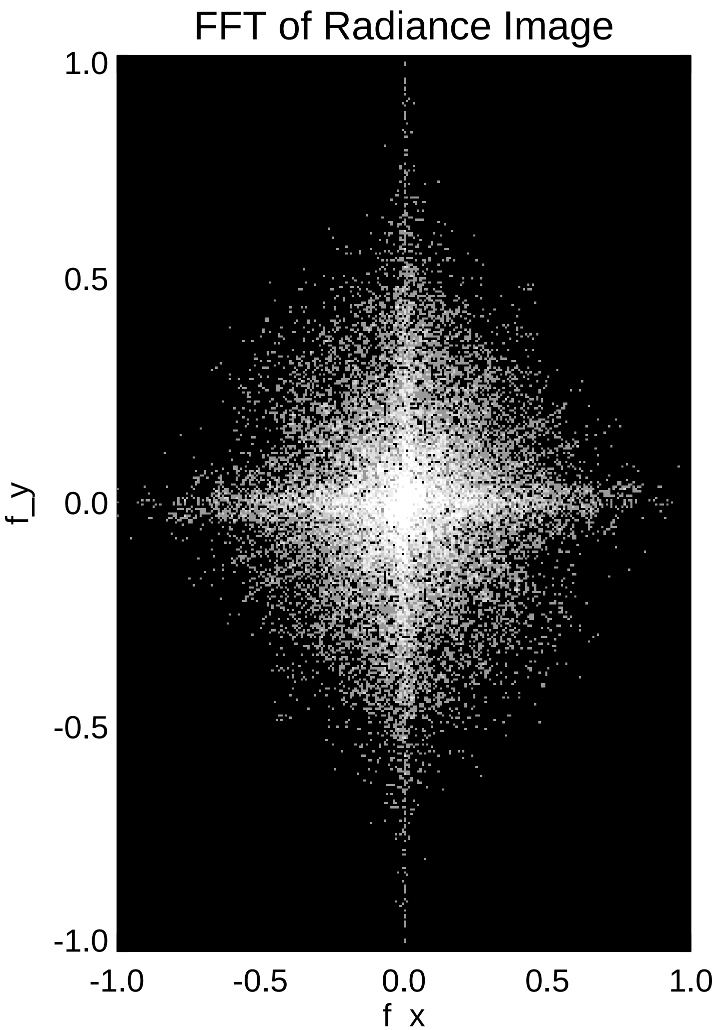
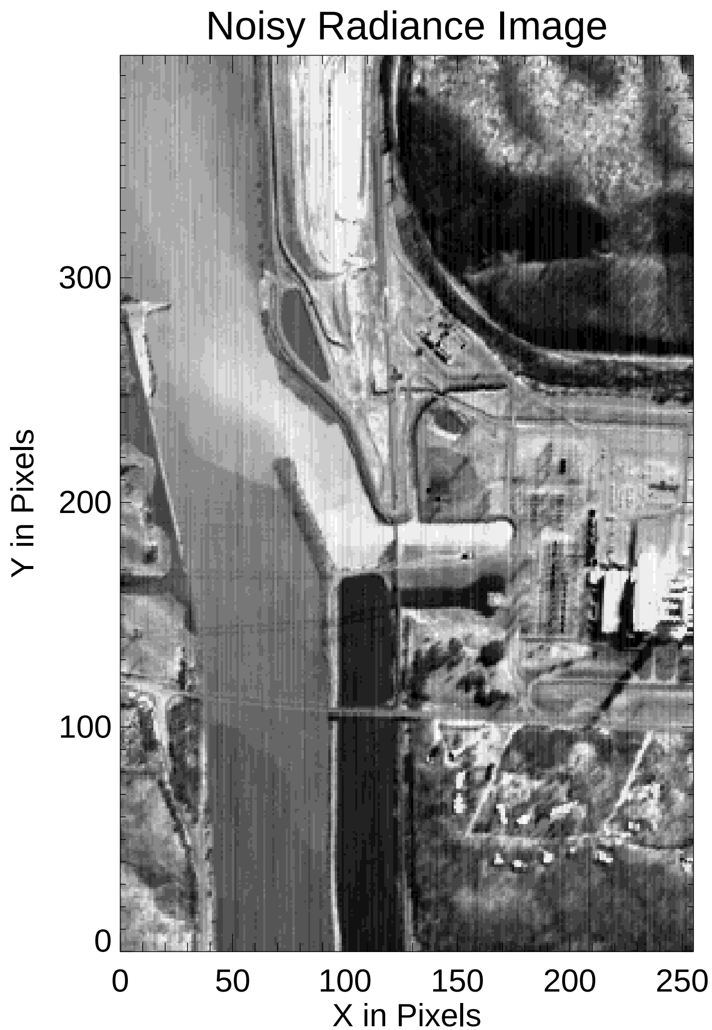




Noise free image.



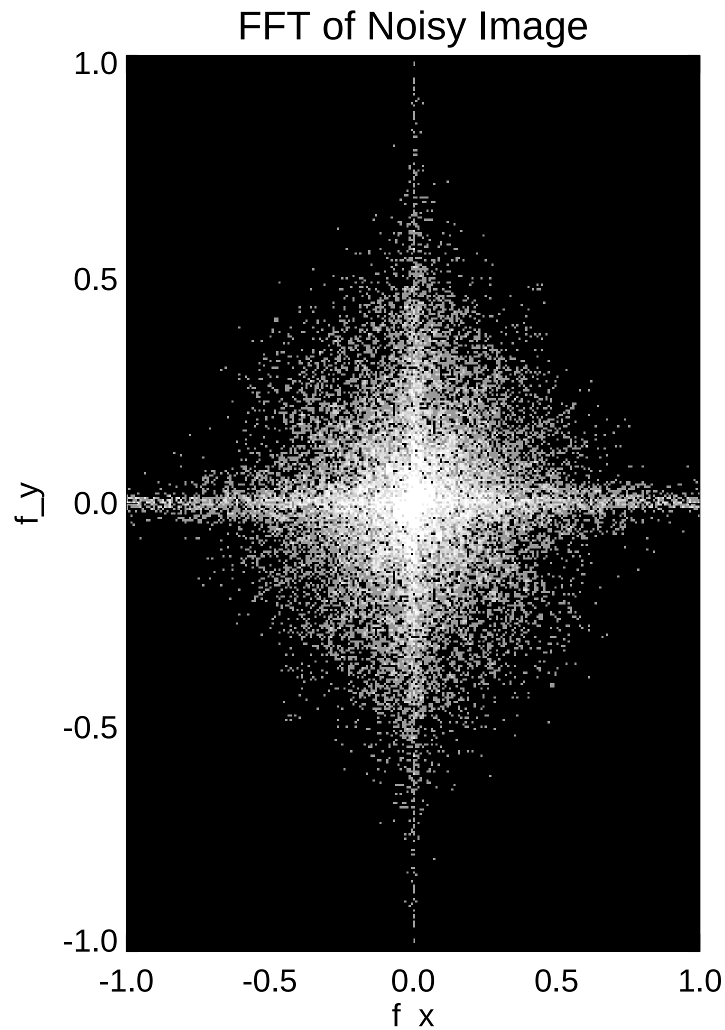
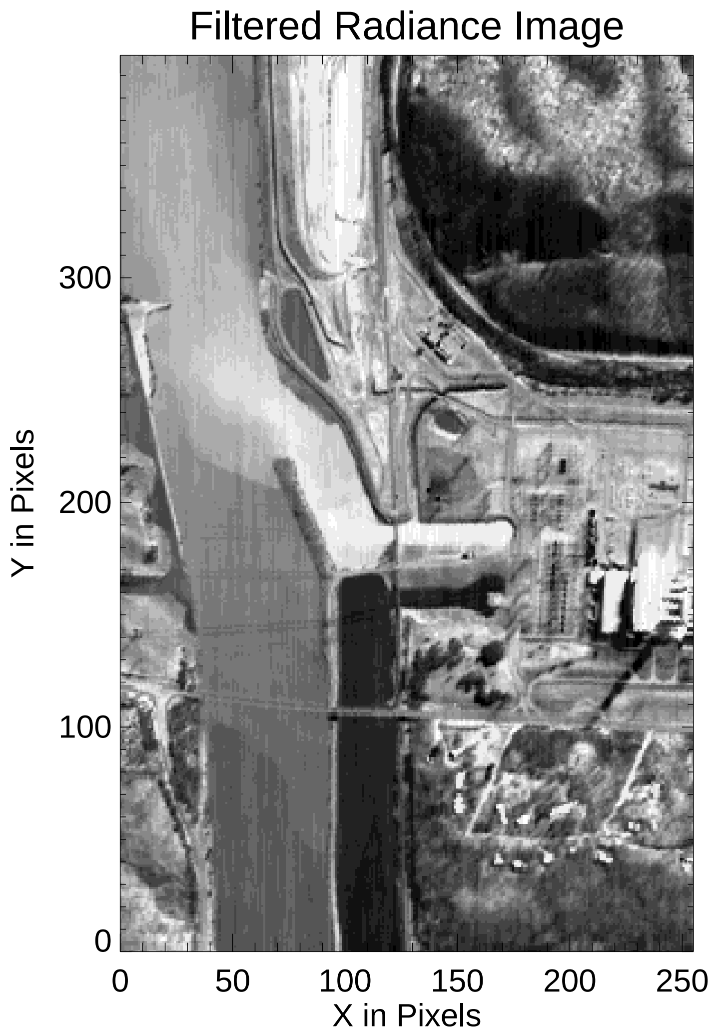
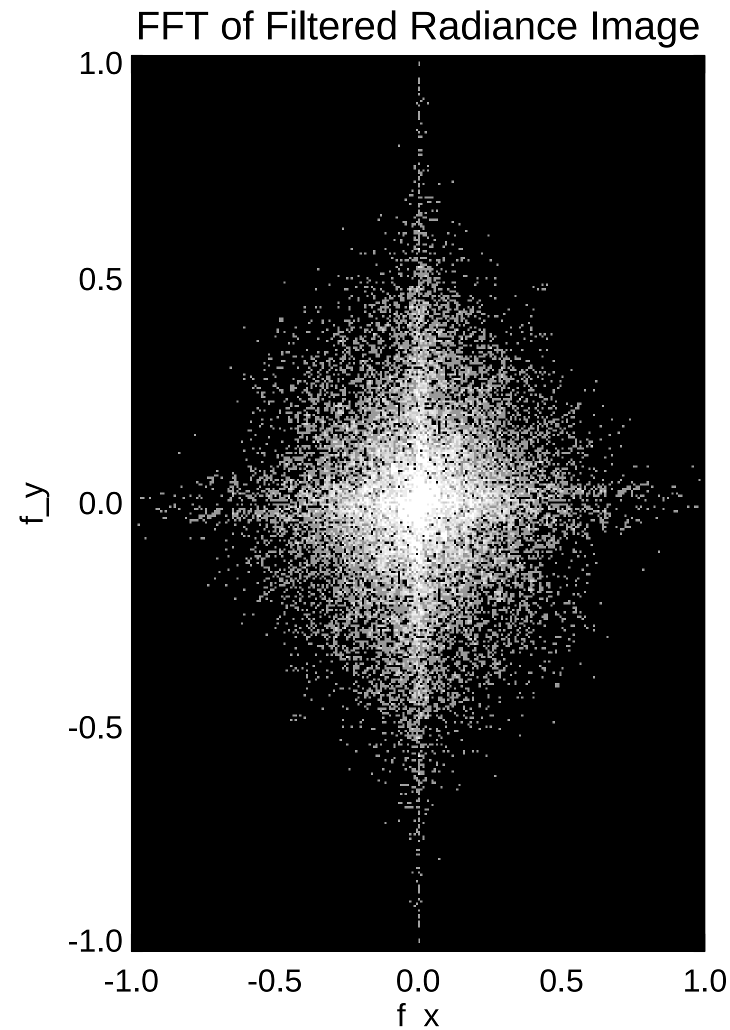


Image with partial correlated noise ($SNR_{cor} = 50$ and $SNR_{Gaus.} = 500$).





Partial removed correlated noise (see $f_y = 0$ line).

Error Metric:

Root Mean Square Error (RMSE) of the difference between the "original" image (with no noise) and the PRCNF filtered noisy image

Results:

The optimization of the proposed filter is given using the following definitions:

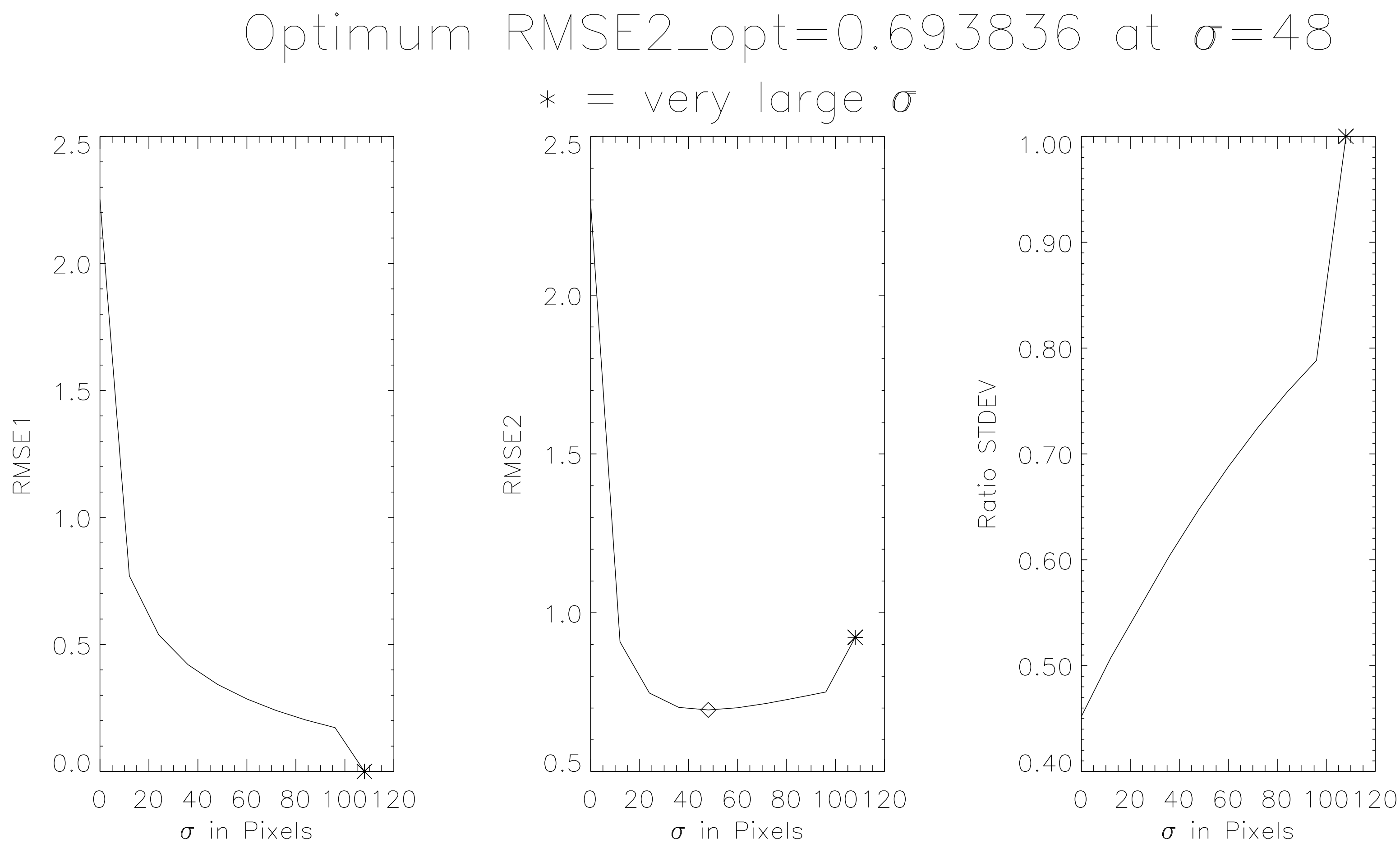
$$RMSE1 = RMSE(I_{ref}(x,y) - FFT^{-1}\left[I_{ref}(f_x,f_y)F_{PRCNF}(f_x,f_y;\alpha,\beta_{opt},\sigma_{opt})\right])$$

$$RMSE2 = RMSE(I_2(x,y) - I_{ref}(x,y))$$

and

$$Ratio_{STDEV} = \frac{STEDEV(I_2(x,y))}{STDEV(I_1(x,y))}.$$

Note we plot $RMSE1$, $RMSE2$ and $Ratio_{STDEV}$ in units of K.



Optimization result for the image example

Subtracting Linear Trends

Question:

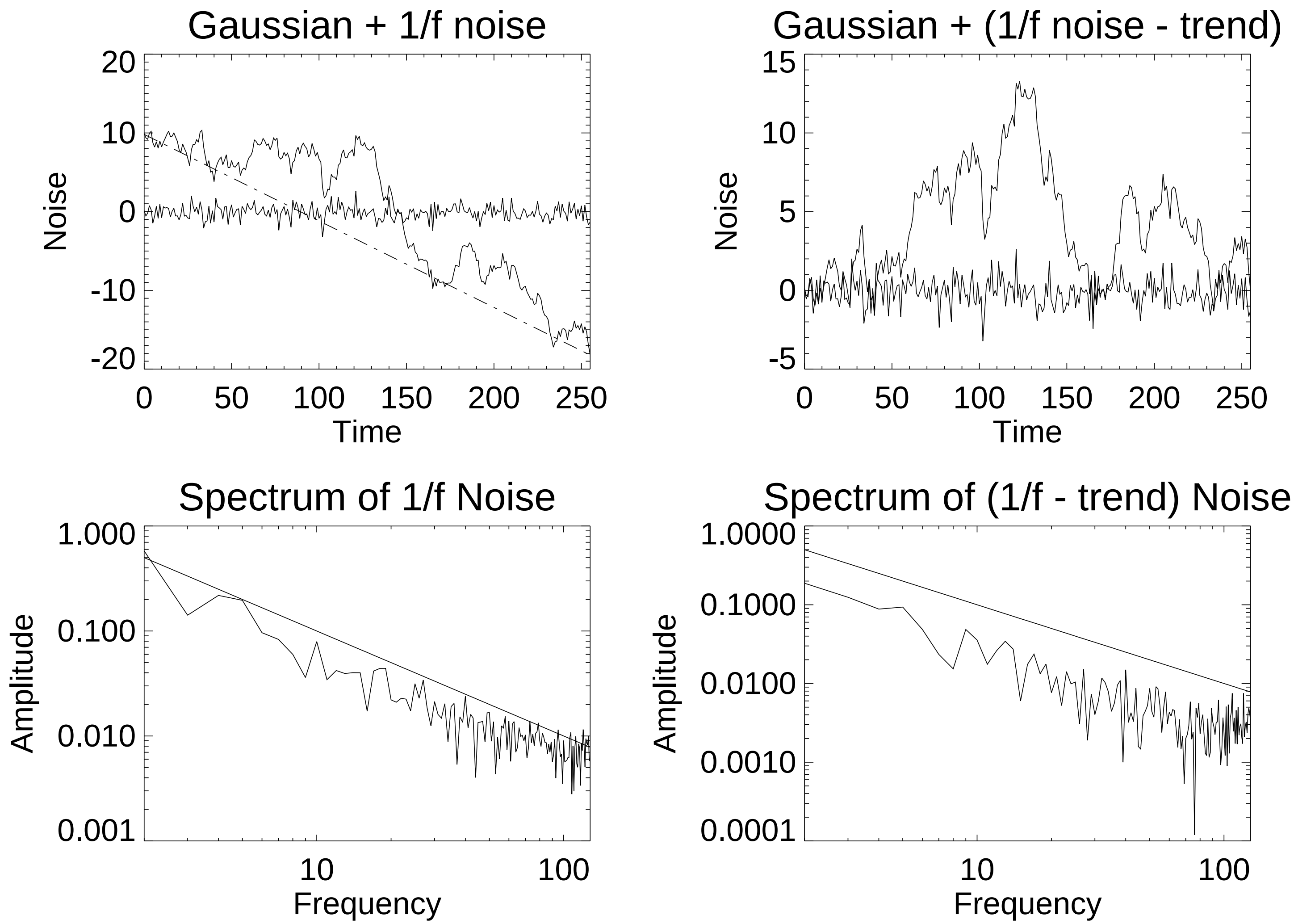
Can we reduce correlated noise using black body temperature measurements?

Steps:

1. Measure at time T_a and pixel $y_a = T_a/\Delta T$, where ΔT is the time between samples)
2. Measure after a scan (at time T_b and pixel y_b)
3. Slope correction:

$$I_{slope}(x,y) = I_1(x,y) - \left[I_1(x,y_a) + \frac{I_1(x,y_b) - I_(x,y_a)}{y_b - y_a} y \right] \qquad (5)$$

4. The slope corrected image $I_{slope}(x,y)$ is then filtered using the $PRCNF$ method.



Simulation of linear trend removal. Note amplitude of noise is reduced.

Simulation Result:

- Assuming $T_a = y_a \Delta T$ and $T_b = y_b \Delta T = 255 \Delta T$ compute the ratio:

$$Ratio_{STDEV} = \frac{\sigma(I_{slope})}{\sigma(I_{noise})},$$

  for a noise with $SNR_{cor} = 50$ and $SNR_{Gaus.} = 500$.

- $Mean(Ratio_{STDEV}) = 0.81$ with standard deviation $\sigma(Ratio_{STDEV}) = 0.248 \Rightarrow$ thus an improvement in SNR is obtained when the linear trend is removed

- Occasionally the $Ratio_{STDEV}$ is above unity, e.g. the noise measurements have both similar large magnitudes but the noise mean is close to zero.

- No improvement if $T_b - T_a >> N_y \Delta T$).

Bottom line:

The observed improvement in the previous image was surprisingly small (0.6754 K vs 0.6938 K) for the case $y_a = 0$ and $y_b = N_y = 255$.

Conclusions

- A method has been developed which reduces the visually disturbing effect of correlated noise in long wave thermal imagery while preserving the image resolution and radiometric accuracy.

- The PRCNF method can be optimized for a given scene if an almost noise free image in another thermal channel (e.g. MWIR) is available, and a noise image in the channel of interest.

References

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